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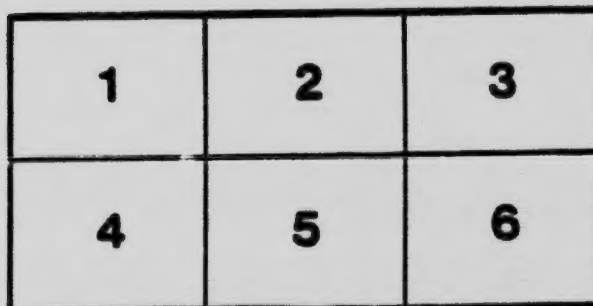
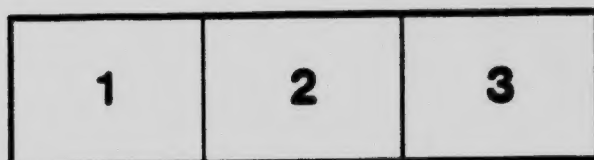
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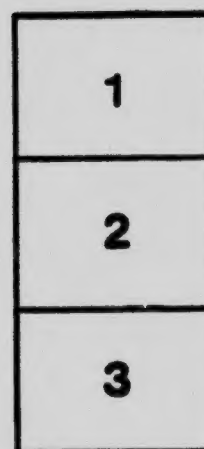
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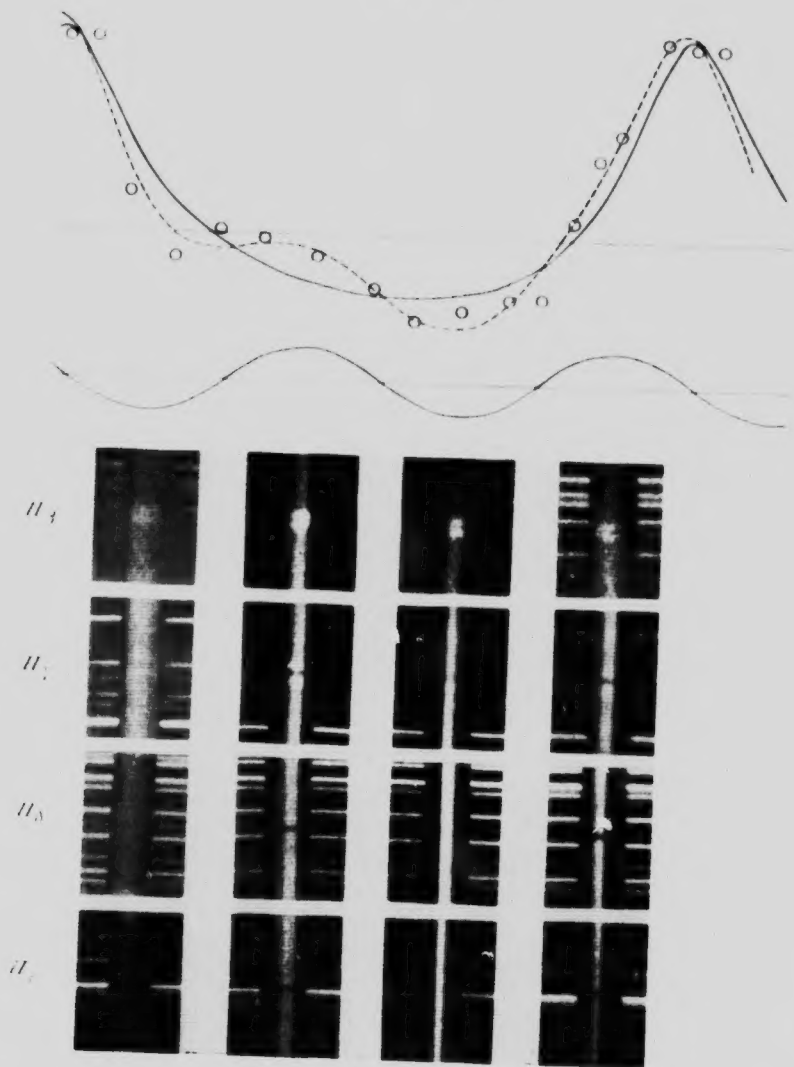
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MAY JUNE, 1910

THE ORBIT OF Φ PERSEI

BY

E. B. CANNON

PLATE XVI.



SPECIMEN SPECTRA AT DIFFERENT POINTS OF CURVE
(Enlarged 20 diameters)

Journal of the Royal Astronomical Society of Canada 1910

THE ORBIT OF ϕ PERSEI

BY J. B. CANNON

ϕ Persei ($\alpha = 1^h 37^m$; $\delta = + 50^\circ 11'$) was announced a binary by Campbell in 1902,* as a result of measures of four plates showing a range of 36 km. per second. The spectrum is in some respects very remarkable and was grouped by Espin† with a large number of others having "remarkable" spectra, and described by him as having "F very bright." For a description of the spectrum as it appeared on the plates obtained here, nothing better can be done than to refer to an article‡ by Campbell, in which he describes spectra of several stars of this type. Speaking of ϕ Persei he says: " H_a is very bright, H_β fairly bright, H_γ and H_δ each of two narrow bright lines, faint, about four tenth-metres apart, H_γ brighter than H_δ ." On our plates we find H_β also consists of two narrow bright lines with a dark fairly well defined centre, and although H_a does not appear on the region photographed, it might be expected from the rapid decrease in intensity of the bright lines and the increase in intensity of the dark lines as we approach the violet end of the spectrum, that H_a will consist of only one bright band. H_β gives only a very faint narrow absorption band, whereas H_δ gives, when any, faint emission lines and H_ϵ none at all. The fact of the presence of both bright and dark hydrogen lines in the spectrum places the star in Vogel's class I_c "although D_1 is not present."§ Besides the hydrogen lines, two other lines were found. $He \lambda 4472$ and K , the latter of these seeming to appear when the star was on the ascending slope of the velocity curve. Both lines, however, are very faint, and, although it is therefore

* *L. O. B.* 20.

† *A. N.* No. 2963.

‡ *Astrophysical Journal*, II., 177.

§ *Ibid.*

impossible to make any positive assertion, the imperfect measurements obtained give velocities corresponding with those of the hydrogen lines.

One hundred and twenty plates of this star were secured altogether between December 1908 and January 1910, taken with the single prism spectrographs, old and new. A striking variation in the character of the spectrum was found in the plates as the star arrived at different points in its velocity curve. The absorption bands were used entirely in the work, an attempt to obtain measures on the bright lines either directly or by means of a spectro-comparator having been found useless.

Table I. contains the lines used with their wave-lengths, and the elements to which they are due.

TABLE I.

	Wave-Length	Element
$H\beta$	4861.527	Hydrogen
	4471.616	Helium
$H\gamma$	4340.634	Hydrogen
$H\delta$	4101.890	Hydrogen
$H\epsilon$	3970.177	Hydrogen
K	3933.825	Calcium

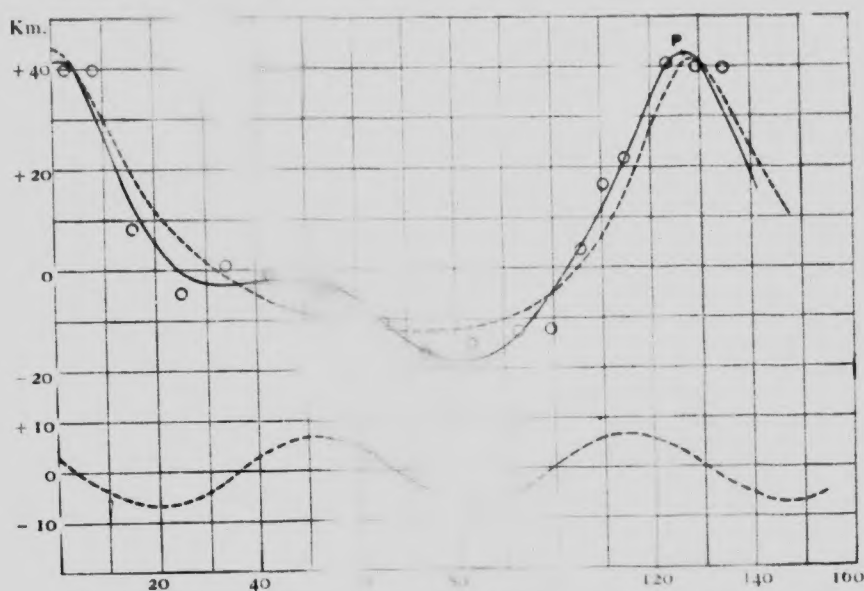
The velocities obtained from the one hundred and twenty plates were plotted together with the velocities given by Campbell from his plates of the years 1898, 1900 and 1901 and gave a period of 126.5 days, which was assumed to be very nearly correct. The curve so obtained was found to be such as could not be satisfied by any simple elliptic motion. On the down slope the curve first dropped below zero, then rose almost to zero and again dropped to nearly 20 km. before rising again to its maximum. So far the only means employed of arriving at such a curve has been the assumption of a secondary disturbance. This is what was done in this case.

The observations were grouped into sixteen normal places, given below, together with the mean phase from final periastron, the mean weight, and residual from finally accepted elements of primary and secondary.

TABLE II.
NORMAL PLACES

No.	Mean Vel.	Mean Phase	O - C	Weight
1	+ 21.8	114.84	+ 0.01	4
2	+ 40.0	123.64	- 0.18	4
3	+ 39.7	2.72	- 2.57	5
4	+ 39.7	8.12	+ 8.53	3
5	+ 8.2	15.63	- 4.89	3
6	- 4.7	25.02	- 4.01	5
7	+ 0.9	33.06	+ 3.67	8
8	- 0.9	43.04	+ 1.12	4
9	- 4.6	53.74	- 1.30	9
10	- 10.8	65.27	- 0.43	3.5
11	- 17.1	73.68	- 0.89	2.5
12	- 15.0	83.08	+ 3.40	6
13	- 13.6	92.69	+ 0.68	4
14	- 1.1	99.10	- 6.53	5
15	- 7.7	105.59	- 0.24	2.5
16	- 5.5	110.29	+ 4.14	4

By means of the graphic method of Dr. King,* the elements of the orbit best suited to the curve were found. At certain

FIG. 1—VELOCITY CURVE ϵ PERSEI—SECONDARY CIRCULAR**Astrophysical Journal*, XXVII, 125, 1908.

regions of the curve the residuals were very large. A secondary circular orbit of one half the period superposed on the primary decidedly improved matters.

The elements of primary and secondary thus found are
Primary :—

$$\begin{aligned} e &= .4 \\ K' &= 25 \text{ km.} \\ \gamma &= + 2.603 \text{ km.} \\ \omega &= 340^\circ \\ T &= 2,418,287.48. \end{aligned}$$

Secondary :—

$$\begin{aligned} K'' &= 6 \text{ km.} \\ T'' &= 2,418,330.62. \end{aligned}$$

(Note :— T'' is the point where the up curve crosses the zero line).

Still the residuals were far from satisfactory and it was thought that the application of Least Squares might do something towards lowering them. In the first solution all the elements of the primary, with the exception of the period, were used and K'' and T'' of the secondary. This resulted in the following corrections to the elements :—

$$\begin{aligned} \delta \gamma &= + .59 \text{ km.} \\ \delta K' &= + 1.47 \text{ km.} \\ \delta e &= + .013 \\ \delta \omega &= + 6^\circ.749 \\ \delta T &= + 2.757 \text{ days} \\ \delta K'' &= + .354 \text{ km.} \\ \delta T'' &= - 3.875 \text{ days.} \end{aligned}$$

and a reduction in Σprr from 1107 to 943. Lack of agreement between ephemeris and observation equation residuals showed the necessity for another solution. This gave the corrections :—

$$\begin{aligned} \delta \gamma &= + .01 \text{ km.} \\ \delta K' &= + .43 \text{ km.} \\ \delta e &= + .016 \end{aligned}$$

$$\begin{aligned}\delta \omega &= + 0.538 \\ \delta T &= + 0.181 \text{ days} \\ \delta K' &= + .43 \text{ km.} \\ \delta T' &= - .168 \text{ days.}\end{aligned}$$

and a second reduction of Σprv from 943 to 918. The probable error of a single plate determined from residuals scaled from the curve was computed and found to be ± 6.12 km. per second. The character of the spectrum of this star hardly justifies so large a probable error. However the agreement between different plates in the same normal place indicates that the fault cannot all be laid to errors in measurement. What the reason may be it is impossible to say, but no doubt the physical condition of so early a class of stars is more or less responsible for what appear to us as irregularities. The probable errors of the elements of the primary were also determined:—

$$\begin{aligned}\text{of } \gamma &\pm .737 \text{ km.} \\ K' &\pm 1.522 \text{ km.} \\ e &\pm .0426 \\ \omega &\pm 6^\circ.19 \\ T &\pm 1.957 \text{ days.}\end{aligned}$$

TABLE III.
SUMMARY OF CORRECTIONS

	Element	Graphic	1st Corrected	2nd Corrected
Primary :	γ	+ 2.603 km.	+ 3.194	+ 3.204
	K'	.25 km.	.20475	.20905
	e	.400	.413	.428
	ω	340°	$346^\circ.75$	$347^\circ.20$
	T	2,418,287.48 J. D.	2,418,290.24	2,418,290.42
Secondary :	P	126.5 days	126.5	126.5
	K''	6 km.	6.35 km.	6.78
	T''	2,418,330.62 J. D.	2,418,326.745	2,418,326.577
	P''	63.25 days	63.25	63.25
	prv	1107	943	918
	$a \sin i$			42,298,000

The residuals of the normal places were now scaled from the corrected primary curve and plotted with a view to obtaining a

secondary of elliptic orbit which might give better results than those from the circular orbit. The curve was treated similarly to the primary, the primary being in the mean time considered correct. Graphically, elements were secured as before and two Least Squares corrections made with the following results.

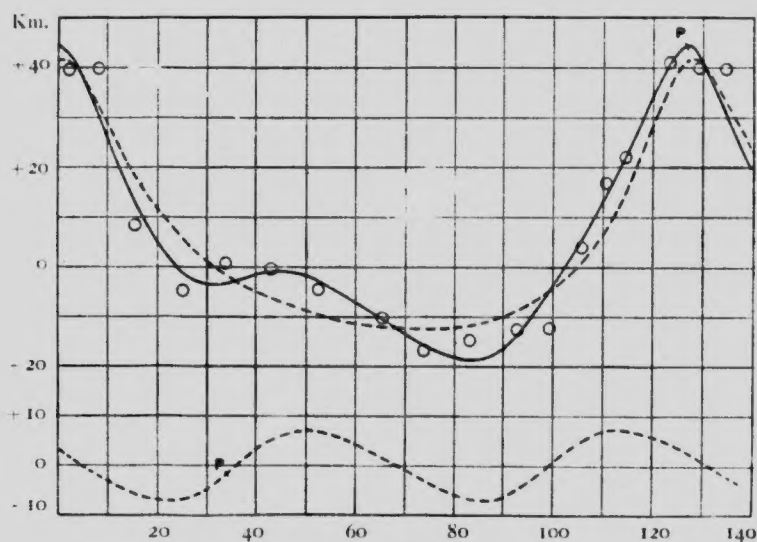


FIG. 2.

VELOCITY CURVE OF Φ PERSEI—SECONDARY ELLIPTICAL

TABLE IV.

	Element	Graphic	1st Correction	2nd Correction
Secondary :	A''	7.8 km.	6.93	6.96
	e''	.05	.145	.107
	ω''	270°	$252^\circ 255$	$257^\circ 145$
	T''	2,418,326.42	2,418,323.48	2,418,324.37
	$p''v''$	.913	.878	.875

The total reduction of $p''v''$ by considering secondary elliptic is .43. Although this reduction is small and the elements only slightly varied from the circular, yet it seems to indicate a slight advantage over the circular.

There are many difficulties which present themselves in connection with this star, and their explanation seems as yet to be far distant. The first question is:—What physical state will produce a spectrum such as this? Although Campbell, in his article already referred to, has spoken of the hydrogen lines γ and δ as being two slightly separated bright lines, the evidence of only some of our spectra can agree with this description. The strong contrast between the central band and the continuous spectrum at certain regions of the curve leaves no doubt whatever of the fact that, that separating band is due to absorption. As stated before, the absorption increases while the emission decreases as we go towards the violet. Perhaps the best suggestion offered as an explanation of this is given by Professor Frost, — quoted by Campbell.* He says:—“Measurements with the spectral photometer have shown that the *general* absorption of the sun's atmosphere is about 1.7 times as great for the violet as for the red rays; the case is doubtless similar for many of the stars, particularly for those having extensive atmospheres; if the same conditions applied to the *selective* as to the *general* absorption, at least a part of the contrast between bright H_a and dark H_γ would be accounted for.”

The variation of the character of the spectrum with the star's position in the orbit was referred to early in this paper, but not gone into in any detail. There seems to be a strange coincidence in the fact that at the crest of the secondary curve the spectrum shows strong absorption while at the trough it shows very weak absorption and, if anything, slightly increased emission. Now, if a satellite about the light-giving star be responsible for this secondary disturbance — this is a mere possibility — the secondary as shown in the curve represents the effect on the primary, and the real course of the satellite's curve will be exactly opposite to that represented by the curve as shown in the figures. That is to say, when the satellite is hastening from us at its greatest speed — the trough of the curve — we have very

* *Astrophysical Journal* II., 177.

weak absorption, and when coming towards us — the crest — we have strong absorption.

Now it will be seen in the figures of the curve that the crest of the secondary, indicating greatest velocity towards us, precedes the crest of the primary, indicating greatest velocity away from us by about fourteen days. Representing this fact in a figure of an ellipse with a satellite revolving about the light-giv-

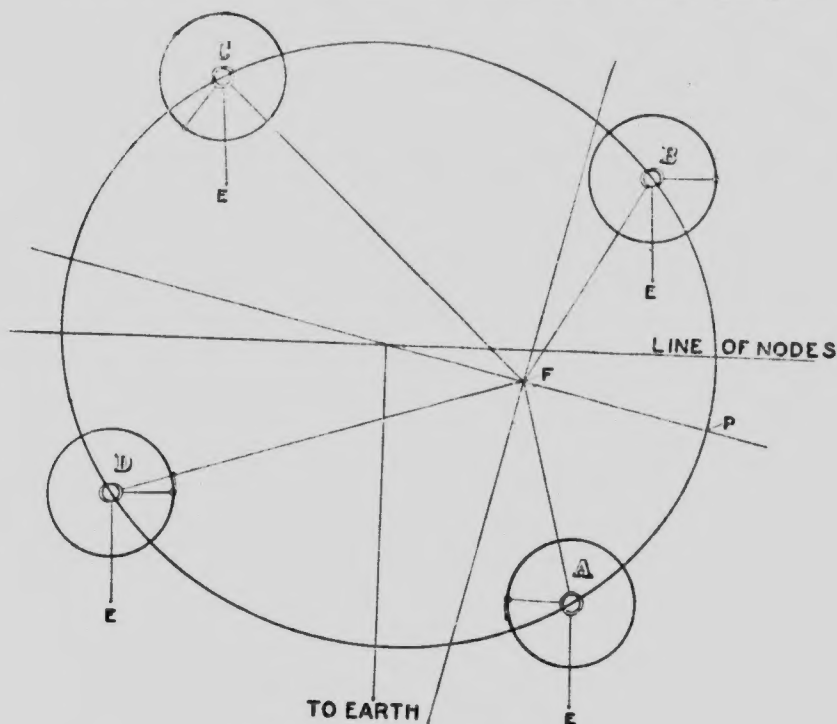


FIG. 3.—ORBIT OF Φ PERSEI

ing body as shown in figure 3, position A , we shall have the central dark body F , and the satellite almost at right angles to the light-giving body. The spectrum of the star indicates a layer of hot, dense hydrogen, producing broad, bright emission bands and outside this a comparatively rare, cool envelope of the same element giving the narrow bands of hydrogen absorption.

Judging by the width of the bands of emission and absorption, the envelope producing the former must be many times as dense as that producing the latter. Now if the tidal action be very prominent in these early stars, and it seems very probable, we may conclude that the effect will be evident almost entirely, comparatively speaking, on the outer absorbing envelope. Returning to position *A*, figure 3, applying terrestrial tidal phenomena we shall have in this position a tide on all sides of the star and a fairly heavy layer of absorbing atmosphere interposed between the emission stratum and the earth. Hence at the position we should have strong absorption.

Let us pass over positions *B* and *C* which, although they will serve our purpose, are not quite so good as *D*. At *D* we have the satellite receding at its highest speed — the trough of the curve — and the satellite and central body *F* acting almost in line. The tide in this case will result in the absorption stratum being much rarefied between the star and the earth. Hence very weak absorption.

The above is only a suggestion of a possible condition which might give some such variation as we find in the character of the spectrum of the star. Some other theory may some time be put forth which will be more satisfactory.

It is proposed at some later date, — perhaps four or five years hence, — to resume the observation of this star and make another determination of its orbit, and especially to note what changes, if any, have occurred in the secondary disturbance. It will be of interest to see if the spectrum then shows the same variation in its character as have been noted in this discussion.

In conclusion I wish to acknowledge my indebtedness to the Director, Dr. King, for his interest in the work, and to Mr. Plaskett for helpful suggestions given me during its progress.

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